Beam Performance and Upgrades of the Storage Ring

Orbit Stability

A beam orbit stabilization project was started in February 2001. Investigations in the first year focused on the survey of fluctuation sources, whereas in the second year, 2002, focused on suppression of the vibration sources we had found.

(i) By observing the correlation between the vacuum chamber vibration and the beam fluctuation, we found that the broad peak around 30 Hz in the vertical beam spectrum is caused by the vibration of an upstream chamber in a unit cell. The vacuum chamber vibrates in a quadrupole magnetic field, then eddy currents are induced on the vacuum chamber wall. The electromagnetic fields induced by the eddy currents shake the electron beam. We have made some improvements on the basis of these results. We reduced the vertical beam fluctuations around 30 Hz by one order of amplitude, as shown in Fig. 1. This improvement is also effective for suppressing the horizontal beam fluctuations from 50 to 100 Hz and the amplitude in this frequency range was reduced by factor three in amplitude.

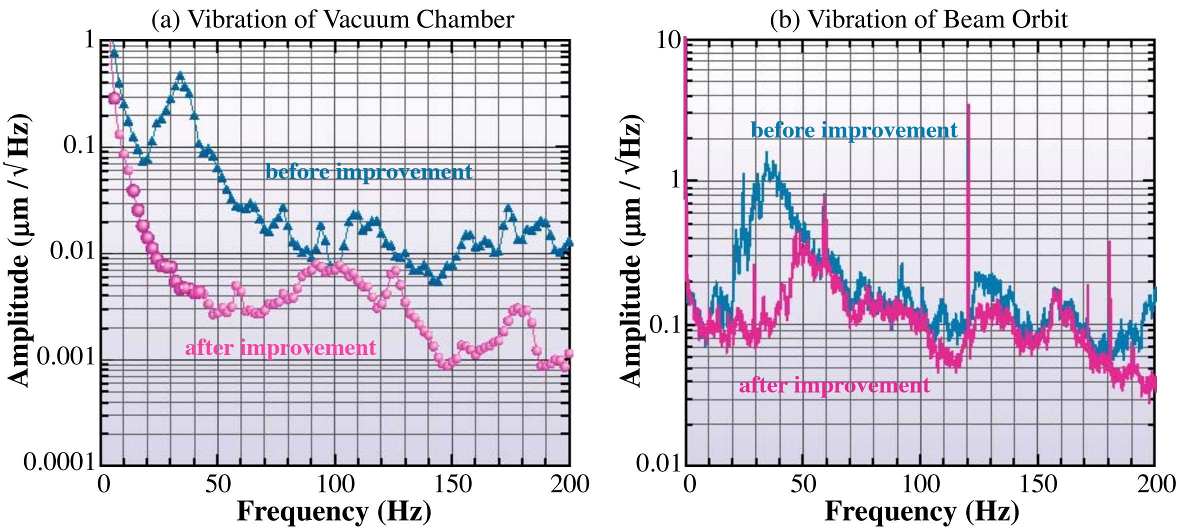

Fig. 1. Vertical vibration of the vacuum chamber and the stored electron beam before and after improvements.

(ii) To suppress the slow orbit drift, we increased the number of air-core type steering magnets with high resolution and low hysteresis from twelve to twenty-four in the summer shutdown of 2002. By this enhancement, we increase the degree of freedom for the correction phase. In principle, this is effective for reducing the slow drift. To avoid the mixing between the circumference change and orbit distortion due to the increment in the steering number, we adopted an algorithm to subtract the contribution of the energy shift from the measured orbit. By using this new periodic correction system, horizontal and vertical orbit deviations were reduced down to about 5 μm in rms for one-day operation.

Top-up Operation

Since 1999 we have been investigating the realization of "top-up operation" in the storage ring at SPring-8. In 2002, we set a target to introduce top-up operation to user time from the autumn of 2003. To meet this time schedule, we are rushing to upgrade a machine control, beam monitors, and an interlock system for radiation safety, and to design and manufacture the new injection bump magnets and their power supplies.

There are two major problems, as follows.

(i) Demagnetization of undulator magnets due to frequent beam injections: This phenomenon occurs due to the loss of injected beams at a narrow vertical aperture of the in-vacuum undulator. Considering both the experimental and simulation results, we are optimizing the design of the collimator system to be installed in the beam transport-line from the booster synchrotron to the storage ring.

(ii) Excitation of betatron oscillation of stored beam by beam injections: An off-axis beam injection is thus adopted as an injection scheme for the storage ring. The bump orbit for the injection is generated by four pulse bump magnets. The magnetic field pattern is a half-sine with a width of about 8 μs. As this bump orbit is not completely closed, the stored beam suffers error kicks while passing through the four bump magnets, and then the betatron oscillation is excited. We found that the oscillation excitation mainly occurred by two effects: (a) One is the effect of nonlinearlity due to sextupoles within the bump orbit. We are considering the correction of error kicks due to this effect by introducing compensation pulse magnets in the ring. (b) The other is caused by the existence of two types of bump magnet. These two have different eddy current patterns on the end plates of bump magnets, which change the shape of the field overshoot. We are now investigating cures for these oscillation excitations, and designing new magnets that have end plates made of insulating material to reduce eddy current effects.

New Optics

There exist several methods to reduce natural emittance. We attempted to reduce the emittance by breaking the achromatic condition imposed on Chasman-Green cells. This method is effective for the case where undulators with a moderate field are used as main insertion devices (IDs). The SPring-8 storage ring just meets this condition, and calculations show that an approximately 20% extra reduction is also obtained by closing all IDs gaps to the minimum, even after breaking the achromatic condition. In the summer shutdown, to realize the new optics we modified cabling of the quadrupoles in the dispersive arc to change the strengths of the quadrupoles while maintaining the phase matching condition over each long straight section. Since September 2002 we have been machine-tuning this new optics (Fig. 2) with the distributed dispersion. We plan to release this new optics to user operation from November 2002. The expected value of emittance is about 2.8 nm·rad with all ID gaps closed.

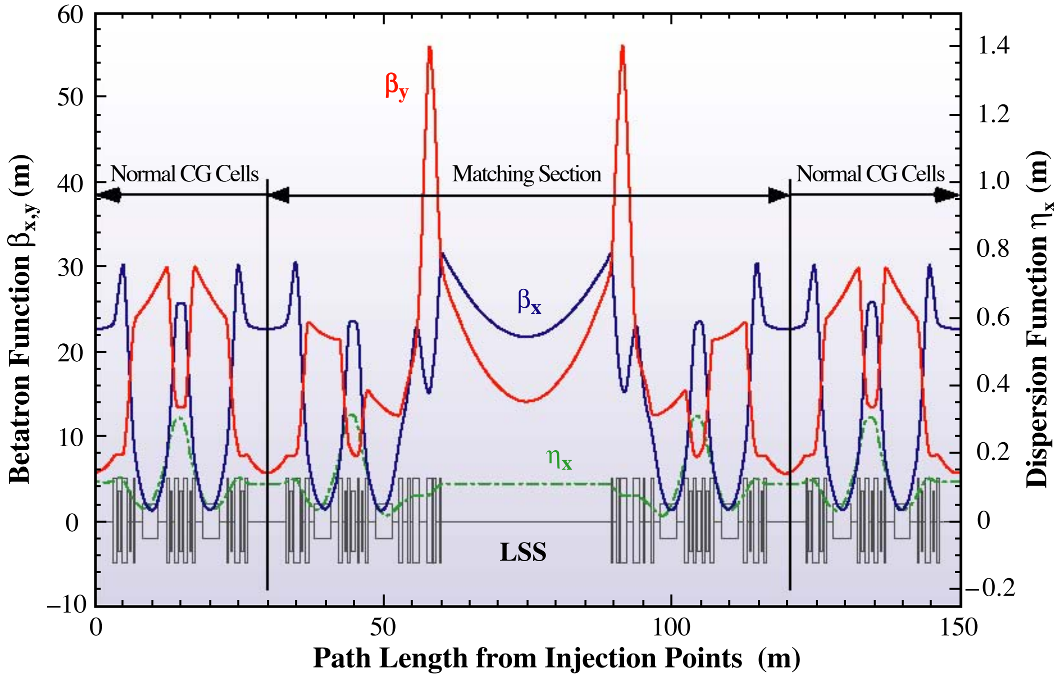

Fig. 2. Optical function for new optics.

Accelerator Diagnostics Beamlines

The accelerator diagnostics beamline #1 (BL38B2), which has a bending magnet light source, is in operation. The visible synchrotron light is used for longitudinal diagnostics of the stored electron beam, such as bunch length and single bunch impurity. Single-bunch impurity is measured by a gated photon counting method that utilizes fast pockels cells for switching light pulses. To improve the extinction ratio or isolation of the light shutter, the optical system was improved so that two pockels cells are arranged in tandem. For the main bunch, we have achieved a sensitivity to satellite bunches in the order of 10^{-10}.

A beam profile monitor based on a phase zone plate has been installed (Fig. 3). Synchrotron radiation from a dipole magnet source is imaged by a single-phase zone plate. The monochromatic X-ray is selected by a double crystal monochromator, which covers the energy range of 4 to 14 keV by Si (111) reflection, while an X-ray zooming tube observes the X-ray image of the electron beam. Results from preliminary experiments show that the observed profile of the beam is affected by a small deformation in the monochromator Si crystals, which was predicted from extensive measurements of the rocking curves of the monochromator. The experiments will resume after improvement in the crystal holders of the monochromator.

The accelerator diagnostics beamline #2 (BL05SS) has a straight section of the storage ring, where IDs for light sources can be installed. Synchrotron radiation from the edges of two bending magnets adjacent to the straight section can also be observed. In 2002, the components of the front end were designed and manufactured, and the design of radiation shielding hutches is in progress. Installation of the front end in the accelerator tunnel and the construction of the hutches will be completed in early 2003.

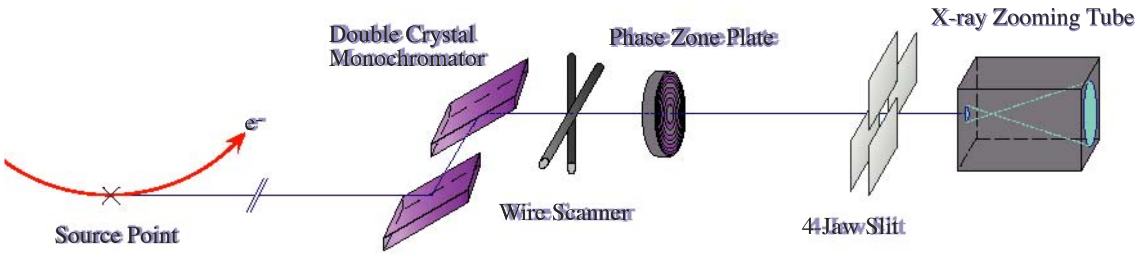

Fig. 3. Optical system of the X-ray imaging of the electron beam.

Bunch-by-bunch Feedback

A bunch-by-bunch feedback system for suppression of transverse beam instabilities is being developed for the storage ring and will be installed in the summer shutdown of 2003. Several instabilities are observed in SPring-8: a multi-bunch instability driven by vertical resistive-wall impedance of small gap in-vacuum undulators, horizontal multi-bunch instability driven by higher order mode impedance of RF cavities, of which horizontal betatron function is increased by one order of magnitude from its design value, and vertical and horizontal single-bunch mode-coupling instabilities driven by broad-band impedance of discontinuities of the beam-pipe wall of the vacuum chamber. Currently, those are suppressed by high chromaticity, 8 in the horizontal direction and 8 in the vertical direction. However, such high chromaticities reduce momentum acceptance of the ring and increases injected beam loss because of its longitudinal phase space mismatch. This beam loss is one of the most serious problems for the top-up operation.

The bunch-by-bunch feedback system uses at least four parallel modules, and each module is composed of two ADCs, one FPGA and two DACs, as shown in Fig. 4. Each module is driven by an 85-MHz clock which is one sixth of the SPring-8 RF acceleration frequency. FPGA is quite faster than DSPs and can handle two 9-tap FIR filter algorithms simultaneously with this frequency. Using this module, we successfully cured a head-tail single-bunch instability that was intentionally destabilized by setting chromaticity negative and obtaining damping time one-order of magnitude shorter than radiation damping.

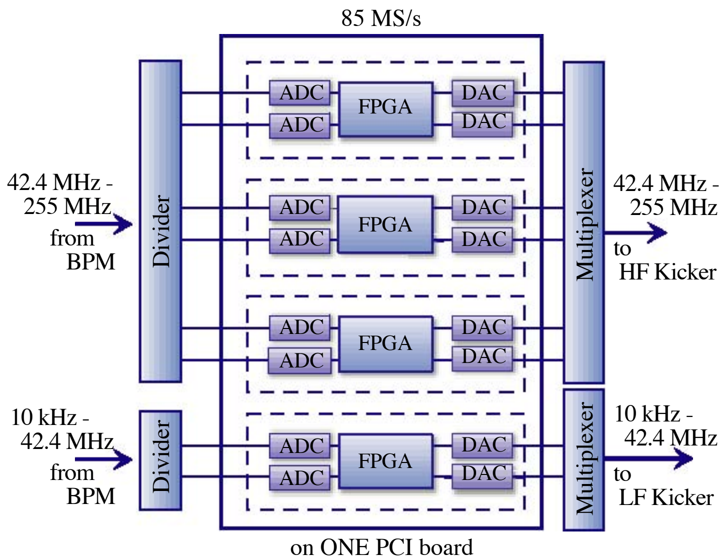

Fig. 4. Block diagram of a digital signal-processing unit with four modules on one PCI board.

Low Energy Operation

In general, the emittance of stored beam is proportional to the square of its energy, and can be reduced by lowering the beam energy. The bunch length is also reduced when we lower the energy. This reduction of emittance and bunch length will open up new opportunities for using brighter synchrotron radiation with shorter pulse lengths at SPring-8. For this aim, we ramped down the beam energy from a design value of 8 GeV and we performed beam injection at 4 GeV. In the ramping-down experiments, we first stored a low-current 5 mA beam in a multi-bunch mode then lowered the energy, step by step, to 4 GeV. At each step of beam energy we measured beam parameters, such as beam size, bunch length, synchrotron frequency, etc., and compared them with expected values obtained from a single-particle picture, as shown in Fig. 5. We found no significant difference between measured and expected values. Beam instabilities were not observed in the above-mentioned current nor in a filling mode. We then performed a beam injection at 4 GeV. To improve the efficiency of beam injection and hence increase the stored current, further studies are planned, such as optimization of the strength of harmonic sextupole magnets.

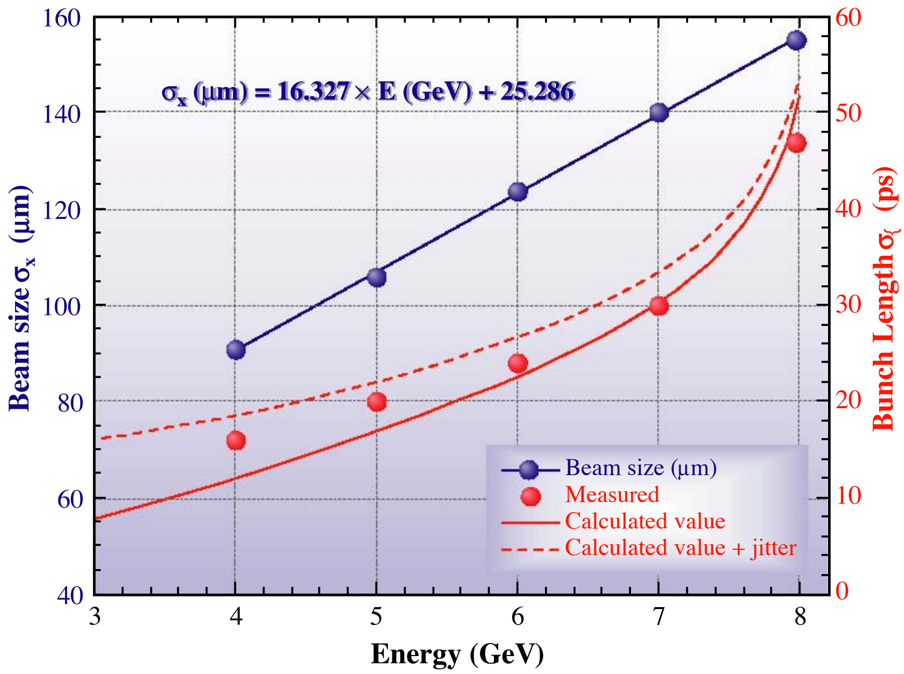

Fig. 5. Horizontal beam size and bunch length as a function of beam energy.